A Combined Micromechanics, Fracture Mechanics, and Statistical Approach for Life Prediction of CMC/MMC

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In order to save weight and increase performance, advanced rocket systems will continue to make use of ceramic matrix composites (CMC's) and metal matrix composites (MMC's). In order to qualify space flight systems, the useful life of the rocket components must be determined. The analysis tool being developed will determine the useful life of rocket components made with CMC's and MMC's.

The technical objectives of this project include the development of a new analysis technique that combines micromechanics, fracture mechanics and statistical principles to model and predict the mechanical response and failure mechanisms of CMC's and MMC's. The proposed technique uses the coefficient of friction at the fiber-matrix interface as the interface parameter which, unlike the interfacial shear stress parameter in the earlier models, can account for the effects of fiber diameter, fiber volume fraction, loading, transverse stress and thermal effects. Thus, a single parameter can now be used to correlate data for different temperatures, fiber volume fractions and loadings, which was not possible with the earlier models.

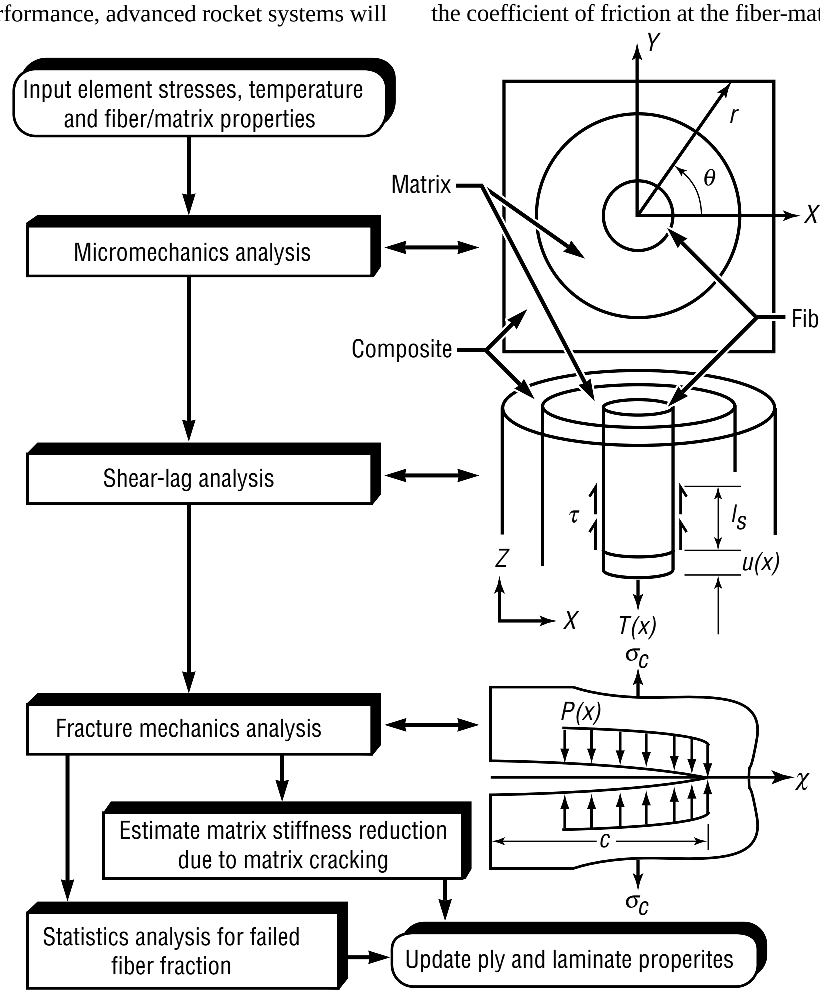

FIGURE 54.—Flow chart of combined micromechanics, fracture mechanics and statistical approach of composite damage prediction.

Phase I result of this project has established an analytical tool for composite damage and life prediction using the techniques described above. Phase I analyses were classical closed-form solutions. Only the material degradation in the fiber direction was considered. A flow chart of Phase I analysis is displayed in figure 54.

The goal of Phase II is for the practical application of the theory. The analytical tool developed in Phase I is applied in the analyses of general structures with multilayer laminates. Finite element analysis has to be applied to the entire structure for obtaining stress and strain information of each element. To predict the failure of a laminate element, the stresses in each ply are estimated by using engineering approaches. The theory developed in Phase I then can be applied to each ply to predict the fiber-failure fraction of each ply. To complete this kind of analysis, one major task is how to estimate the material damage in the off-fiber direction since transverse matrix cracking is the initial damage occurring in the composite ply. In Phase II studies, the volume element damage mechanics (VEDM) model is planned to be used to predict the matrix cracking in the off-axis plies. Figure 55 shows the flow chart of the failure prediction of a laminate element.

The successful completion of this project will result in the development of a new, general purpose analytical tool called CMLife, for the fatigue life prediction of laminated and textile ceramic matrix and metal matrix composites and will, thereby, fulfill a critical need in the design of high-temperature components at NASA and in

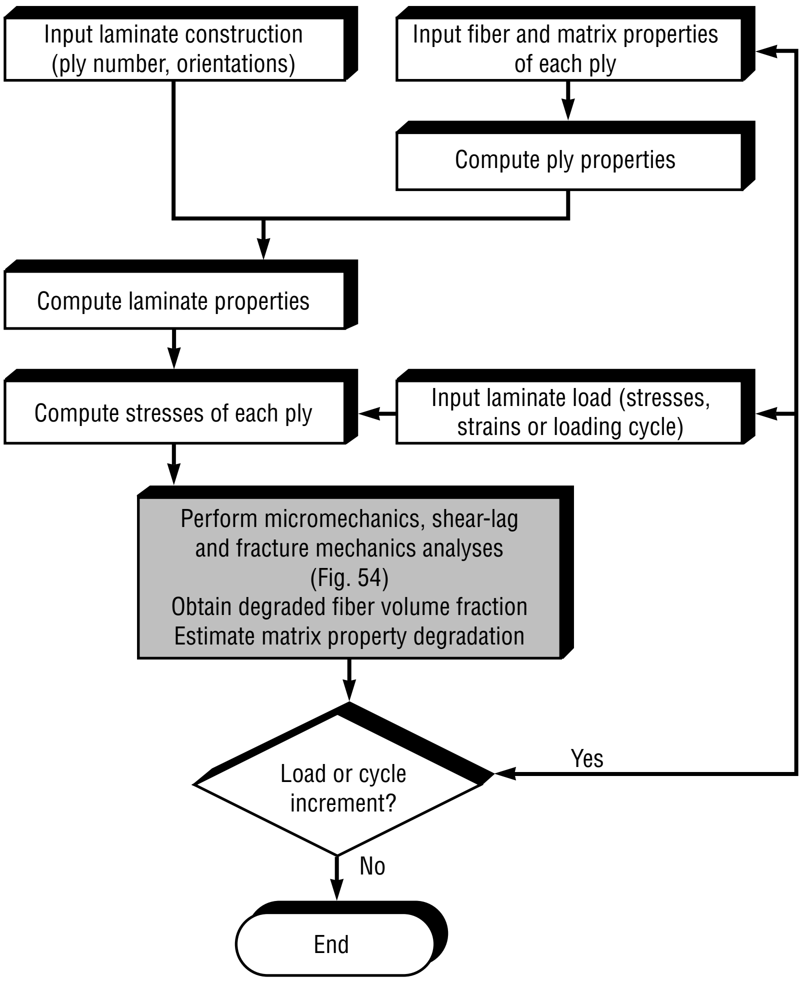

Figure 55.—Flow chart for failure prediction of a laminate element.

industry. It will have a menu-driven, point-and-click user interface which will enhance its appeal to engineers and designers at NASA and in industry. Also, it will be seamlessly integrated with a commercial finite element code ABAQUS for life prediction of CMC's and MMC's.

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Biographical Sketch: Dr. James Min is a member of the Structural Integrity Branch in the Structural Analysis Division of the Structures and Dynamics Laboratory at MSFC. Min joined the Marshall Center in 1989. His current activities include stress, fracture/fatigue, durability and damage tolerance analysis of metallic and composite structures. Min received a B.S. in mechanical engineering from Han Yang University, Seoul, Korea. He also holds a M.S. in engineering mechanics, civil engineering, and materials science and a Ph.D. in mechanical engineering from University of Illinois, Chicago.